526 Rec'd PCT/PTO 21 DEC 2000

FORM PTO-1390 REV. 5-93 US DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**		ATTORNEYS DOCKET NUMBER **P00,1754** U.S. APPLICATION NO. (if known, see 37 CFR 1.5) 09/720283
INTERNATIONAL APPLICATION NO. **PCT/DE99/01835**	INTERNATIONAL FILING DATE **23 JUNE 1999**	PRIORITY DATE CLAIMED **23 JUNE 1998**
TITLE OF INVENTION **DYNAMIC BANDWIDTH ASSIGNMENT IN AN ATM TRANSMISSION SYSTEM**		
APPLICANT(S) FOR DO/EO/US **GUNNAR HAGEN**		

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay.
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of International Application as filed (35 U.S.C. 371(c)(2)) - drawings attached.
   a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2) - drawings attached.
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. §371(c)(3))
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98; **(PTO 1449, Prior Art, Search Report, References).**
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included. **(SEE ATTACHED ENVELOPE)**
13. ☒ Amendment "A" Prior to Action and Submission of Substitute Specification.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☒ A change of address letter attached to the Declaration.
16. ☒ Other items or information:
    a. ☒ Submission of Drawings and Request for Approval of Drawing Changes
    b. ☒ EXPRESS MAIL #EL655302903US dated December 21, 2000.

JC01 Rec'd PCT/PTO 21 DEC 2000

U.S. APPLICATION NO. (if known, see 37 C.F.R. 1.5) 09/720283	INTERNATIONAL APPLICATION NO. PCT/DE99/01835	ATTORNEY'S DOCKET NUMBER P00,1754

17. ☒ The following fees are submitted:	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5): Search Report has been prepared by the EPO or JPO .... $860.00 International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) .. $690.00 No international preliminary examination fee paid to USPTO (37 C.F.R. 1.482) but international search fee paid to USPTO (37 C.F.R. 1.445(a)(2) .... $710.00 Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2) paid to USPTO .... $1000.00 International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) .... $ 100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).	$	

Claims	Number Filed	Number Extra	Rate		
Total Claims	10 - 20 =	0	X $ 18.00	$	
Independent Claims	02 - 3 =	0	X $ 80.00	$	
Multiple Dependent Claims			$270.00+	$	

	CALCULATIONS	PTO USE ONLY
TOTAL OF ABOVE CALCULATIONS =	$ 860.00	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 C.F.R. 1.9, 1.27, 1.28)	$	
SUBTOTAL =	$ 860.00	
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +	$	
TOTAL NATIONAL FEE =	$ 860.00	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). $40.00 per property +		
TOTAL FEES ENCLOSED =	$ 860.00	
	Amount to be refunded	$
	charged	$

a. ☒ A check in the amount of $ 860.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ____________ in the amount of $ ________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 50-1519. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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BOX PCT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY-CHAPTER II

APPLICANT:	HAGEN, G.
ATTORNEY DOCKET NO:	P00,1754
INTERNATIONAL APPLICATION NO:	PCT/DE99/01835
INTERNATIONAL FILING DATE:	23 JUNE 1999
PRIORITY DATE CLAIMED:	23 JUNE 1998
INVENTION:	DYNAMIC BANDWIDTH ASSIGNMENT IN AN ATM TRANSMISSION SYSTEM

AMENDMENT "A" PRIOR TO ACTION AND SUBMISSION OF SUBSTITUTE SPECIFICATION

Assistant Commissioner for Patents
Washington, DC 20231

Sir,

Applicant herewith submits an amendment and substitute specification in the above-referenced PCT application, and respectfully requests entry of same prior to examination in the United States National Examination Phase.

IN THE SPECIFICATION

Cancel the specification as filed and substitute therefore substitute specification provided herewith.

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IN THE CLAIMS

Cancel claims 1 - 9 as filed and substitute therefore new claims 10 -19 as follows:

-- 10. A method for dynamic bandwidth assignment in an ATM transmission system having a hub station and at least one remote station in communication with each hub station, the method comprising the steps of:

acquiring local fill data which reproduces states of buffers in each remote station;

forwarding the fill data to the hub station;

calculating bandwidth parameters in each remote station for a transmission from another remote station to the hub station as a function of the fill data; and

assigning the calculated bandwidth parameters to each remote station.

11. The method of claim 1, wherein the step of calculating comprises calculating MAC parameters and assigning them to each remote station.

12. The method of claim 2, wherein the step of calculating further comprises using predetermined connection or transmission parameters which reproduce actual current characteristics of the air interface.

13. The method of claim 12, further comprising the step of using the fill data to provide information on a frequency with which a predetermined fill of the buffer to each remote station has been exceeded within a past period.

14. The method of claim 13, further comprising the step of storing the calculated bandwidth parameters for a number of cycles.

15. An ATM system comprising a hub station and at least one remote station in communication with the hub station via an air interface, the system comprising:

a buffer in each remote station, the buffer capable of dispatching data therefrom;

a control channel in each remote station, the control channel capable of sending fill data which reproduces the state of the buffer of a remote station to the hub station; and

an arithmetic unit capable of calculating bandwidth parameters for each remote station at least as a function of the fill data, whereby the hub station assigns bandwidth parameters to each remote station via the control channel.

16. The ATM system of claim 15, wherein the arithmetic unit calculates MAC parameters and the hub station assigns the parameters to each remote station.

17. The ATM system of claim 16, wherein the arithmetic unit calculates bandwidth or MAC parameters based upon predetermined connection or transmission parameters which reproduce current characteristics of the air interface.

18. The ATM transmission system of claim 17, wherein the fill data provides information on a frequency with which a predetermined fill of the corresponding buffer has been exceed with a past period.

19. The ATM transmission system of claim 18, wherein the hub station comprises a circular buffer for storage of bandwidth parameters of a number of cycles accessible by the arithmetic unit in order to achieve a predetermined regulation characteristic of the bandwidth assignment. - -

IN THE ABSTRACT

Cancel the Abstract as filed and substitute therefore the following Abstract of the Disclosure:

- - ABSTRACT OF THE DISCLOSURE

An ATM (asynchronous transfer mode) method and system for dynamically assigning bandwidth on the common air interface, based upon connection parameters, actual buffer levels of remote stations, the transmission characteristics of the radio range, and strategies for assessing charges. The bandwidth is assigned so that the transmission volume of ATM conformal traffic in the uplink direction of wireless point-to-multipoint configurations is optimized while taking these configurations and common boundary conditions into consideration. The method provides a central station and at least one remote station which can communicate with the central station over a common air interface. Each remote station comprises a buffer for data to be transmitted. Each remote station transmits level data which emulates the state of the buffer of the respective remote station to the central station via a control channel. The central station comprises an arithmetic unit which calculates the bandwidth parameters for the individual remote station at least according to the transmitted level data. The central station then assigns the bandwidth parameters to the individual remote stations over the control channel. - -

REMARKS

A substitute specification is provided herewith which makes editorial changes in order to conform to standard US patent practice. A marked-up copy of the specification is herewith provided reflecting the changes made.

In addition, the claims have been amended to more clearly set forth the subject matter of Applicant's invention.

Applicant submits that this application is in proper condition for examination in the United States National Examination Phase, which action is respectfully requested.

Respectfully submitted,

Steven H. Noll

Steven H. Noll (Reg. No. 28,982)

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Substitute Specification

- -Dynamic Bandwidth Assignment In An ATM Transmission System

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention generally relates to ATM (asynchronous transfer mode) transmission systems. In particular, the present invention relates to dynamic bandwidth assignment in ATM transmission systems.

Discussion of the Related Art

For certain applications in wireless transmission technology, point-to-multipoint configurations are the most economic solution from the point of view of equipment. In this configuration, a hub station can communicate with a number of so-called remote stations, typically situated in a cell, in full duplex mode via an air interface. In this arrangement, a two-point channel on a single transmission medium is adequate even in the uplink, i.e. from the various remote stations to the hub station. The transmission bandwidth of this channel is physically limited in correlation with the frequency spectrum provided. In each case a number of logical channels are made available for communication between a certain remote station and the central hub station by multiplexing this two-point channel.

The total bandwidth of the physical channel can be distributed asymmetrically and, in accordance with demand aspects, dynamically to the logical channels by means of so-called asynchronous methods, such as asynchronous transfer mode (ATM). For

this distribution, criteria must be used in accordance with which the bandwidth requirement of a certain remote station can be weighted with respect to the competing requirement of other remote stations. The more accurately the bandwidth requirement can be met, the more economically the physically limited bandwidth will be for communication purposes.

The conditions under which the problem of dynamic bandwidth allocation is created have become apparent in recent times. In particular, this problem exists in the uplink, which can be a bottleneck at the central hub station in the point-to-multipoint configuration. The prerequisite for achieving the highest possible gain in throughput are, among other things, a mixture of various classes of traffic and the largest possible ratio between remote stations and hub stations referred to the physical bandwidth per cell. From the point of view of the operator, a charging structure predominantly oriented toward data volume actually conveyed instead of the bandwidth made available proves to be competitive.

In summary, these conditions can be overcome by introducing ATM-based transmission in the so-called "fixed wireless broadband access" segment. With respect to the wireless domain, ATM offers the best solution with respect to bandwidth limitation on the air interface, which can only be countered by reducing the size of the radio cells, in contrast to alternative transmission technologies and other network areas.

Therefore, the present invention answers the question of how the total throughput of ATM traffic can be optimized in a simple manner by means of a dynamic bandwidth allocation for the logical channels.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method and system for dynamic bandwidth assignment in an ATM transmission system.

It is another object of the invention to provide a method and system for calculating media access control (MAC) parameters in a hub station and assigning them to individual remote stations.

It is a further object of the invention to provide a method and system for reproducing the frequency when a predetermined fill relating to a corresponding buffer has been exceeded via a remote station within a past period.

It is yet another object of the invention to provide a method and system for calculating bandwidth parameters that can be temporarily stored for a number of cycles in order to be able to achieve a predetermined regulation characteristic.

These and other objects of the invention will be apparent upon careful review of the following disclosure, which is to be read in conjunction with review of the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a block diagram of an ATM transmission system according to the present invention;

Figure 2 shows a flowchart of the acquisition, calculation and assignment process according to the present invention; and

Figure 3 shows an exemplary embodiment of a modulator and a demodulator according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will now be explained in greater detail with reference to exemplary embodiments and to the accompanying drawing figures of the drawings.

The general configuration of an ATM system according to the invention is shown in Figure 1. Figure 1 shows two remote stations 1, 2 and one hub station 3 of an ATM (asynchronous transfer mode) transmission system. The remote stations can communicate with the hub station in each case via an air interface 4. The remote stations can also communicate with the hub station in each case via a bidirectional control channel 13, 13' apart from the actual transmission channel 14, 14'. In contrast to the actual data transmission channels 14, 14', the bidirectional control channel 13, 13' is used for transmitting control information which can contain bandwidth parameters and MAC parameters.

Each remote station 1, 2 has a buffer 5 for data to be sent out therefrom, which is connected to a modulator 6 which modulates the data of the buffer 5 to a carrier frequency in accordance with a predetermined modulation method. In this arrangement, a controller 7 which, on the one hand, can set the modulator 6 and the demodulator 8 to certain parameters and, on the other hand, can read certain parameters such as fill values of the buffer 5, in particular from buffer 5, is connected to the buffer 5, the modulator 6 and a demodulator 8.

At the hub station 3, an arithmetic unit/controller 10 connected to the modulator 9 and the demodulator 11, which is also connected to a circular buffer 12 in which values of bandwidth parameters of a number of calculation and assignment cycles can be temporarily stored.

Due to the network characteristic, the data needed for bandwidth control are initially made available and distributed in space, in the remote stations 1, 2. After their local decentralized acquisition in the remote stations 1, 2. The data is combined in a centralized decision entity which is resident in the hub station 3 due to the arithmetic unit/controller 10.

A decisive factor for an ATM-conformal function is that suitable parameters for describing the buffer fills are needed. These parameters will be called "threshold crossing events" (TCE) herein. The TCE parameters are inseparably accompanied by a certain organization of the ATM traffic and values derived from these TCE parameters, which are called "urgency descriptors" (UD), are combined with the connection parameters agreed in the traffic contract and with the parameters which characterize the transmission performance of the radio link. The prerequisite for this is that the local buffer output at the remote stations 1, 2 can be controlled and is deterministic in its behavior. Using suitable algorithms, values are derived on the basis of the abovementioned parameters, which characterize the allowed proportion of bandwidth in the uplink, i.e. from the respective remote station 1, 2 to the hub station 3.

These basic values also describe the manner in which the transmission medium can be accessed (MAC descriptor, MAC parameters, etc.). These basic values are conveyed from the central arithmetic unit/controller 10 in the hub station 3 to the local control entities controllers 7 in the remote stations 1, 2 so that the necessary adjustments to the buffer management and to the modulators 6 can be carried out there. In this process, block retransmission requests are also taken into consideration which compensate for errors in the transmission of non-real-time data, and the

overhead for special coding methods which are used for conveying real-time data as a function of the environmental conditions. Correspondingly, the demodulator 11 is then also set at the hub station 3. Since these adjustments must be made in alignment with one another in time, a certain sequence is ensured via the exchange of acknowledgements via the bidirectional control channel 13, 13'. These data are exchanged via permanent bidirectional control channels 13, 13' between the remote stations 1, 2 and the central hub station 3.

Referring to Figure 2, the sequence for acquiring fill parameters, and of the calculation and assignment of bandwidth parameters will now be explained. Firstly, the threshold crossing events (TCEs) are acquired locally in the remote stations 1, 2 in a step S1. From these TCEs, urgency descriptors (UD) are then determined in a step S2 and transmitted to the hub station 3. In a step S3, the hub station 3 calculates from these and other parameters bandwidth parameters for the logical channels (logical channel bandwidth values, LCB) and the MAC descriptors and transmits them back to the controllers 7 of the remote stations 1, 2. When the newly assigned bandwidth (LCB) is smaller than the previously set bandwidth, new queue weight factors are set in the remote stations 1, 2 in a step S4, which factors are a final result of the calculations and are indirectly used for setting the cell rates at the interface between buffer and modulator. In a step S5, the modulator is then set for a bandwidth release and a confirmation is transmitted to the hub station 3 via the bidirectional control channel.

The hub station 3 then transmits a ready message for use of the new bandwidth parameters (LCB) back to the remote stations 1, 2 in a step S6. In a step S7, the modulator 6 of a remote station is then set for a bandwidth occupation if the new

bandwidth parameter for the corresponding remote station 1, 2 is greater than the old bandwidth parameter (LCB). The new queue weight factors (QWF) are then also set correspondingly (step S8).

The data generated in the remote stations 1, 2 includes: threshold crossing events (TCE) which indicate that a certain fill has been exceeded in the past period relating to individual queues or a group of queues within a buffer; urgency descriptors (UD) which are derived from the threshold crossing events (TCE) and the classes of traffic associated with the queues, thereby representing a condensation of information which is aimed for simple comparability; and queue weight factors (QWF) which are the final results of calculations and are indirectly used for setting the cell rates at the interface between buffer 5 and modulator 6.

The following data are generated In the hub station 3: connection parameters as part of a so-called traffic contract, the observance of which must be ensured in every case, such that when a connection is newly set up, these can produce an additional bandwidth request which can make it necessary to displace lower-value traffic of adjacent remote stations; logical channel bandwidth values which describe the bandwidth granted to a connection from a remote station 1, 2 to the hub station 3, which in order to achieve a certain regulation characteristic, these values are saved over a number of cycles in a circular buffer 12 which can be accessed by the arithmetic unit/controller 10 of the hub station 3; environmental condition descriptors which describe the current actual transmission characteristic of the air interface 4, and the error protection methods selected as a function of this have an influence on the bandwidth needed; configuration data, for example “encryption over the air”, which can

have an influence on the bandwidth needed; and weight factors derived from charging strategies for determining the bandwidth parameter values for the logical channels.

Figure 3A shows an actual implementation of a modulator and a demodulator which can be used in the present invention. The design shown in Figure 3A can be used in various switch configurations and with modulators/demodulators which may be different and both in the remote station as in the hub station. A mixed FDMA/TDMA method, for example, is of advantage as radio transmission technique for the air interface 4.

The arrangement can be implemented on the surface of two boards equipped on one side or one board equipped on both sides. For the purpose of integration in the ATM switch 36140/144 shown, a connection to the backplane busses (cell bus technology) is provided additionally on the modulator side (MOD) in addition to coupling the local power supply unit (PSU) to the centralized power supply of the switches. For this purpose, so-called FPGAs and the CUBIT-Pro components by the Transwitch company are used which are here collectively called "bus interface to cell bus and control bus". The cell buffer for the non-real-time traffic or the ATM traffic to be shaped is constructed with SDRAMs. The rule-based buffer management is carried out with the aid of the Siemens HL standard component ABM (PXB 4330) which is controlled centrally via its local bus connection. This component additionally has a direct interface (Utopia) with the modulator/demodulator unit and the bus interface to the cell bus for the ATM user traffic. However, in real life ATM user traffic can be forwarded between these interfaces directly via an internal bypass, i.e. by bypassing the buffer, as shown in Figure 3B. Because of its high power dissipation, the modulator/demodulator unit is

taken into consideration under special requirements for the EMC compatibility, particularly in configuration technology. It is centrally controlled via a logical control interface. To control the components involved and the ATM traffic, the so-called voyager processor by the Motorola company is used which is connected to the components via its standard interfaces (Utopia, local bus, serial interface).

Thus, according to the present invention, the bandwidth at the air interface is dynamically assigned on the basis of connection parameters, current buffer fills, the transmission characteristics of the air interface and charging strategies, in such a manner that the transmission volume of ATM-conformal traffic in the uplink of wireless point-to-multipoint configurations is optimized, taking into consideration these and other boundary conditions. Following the ATM layer model, this can be considered to be motivated as a control of characteristics of the physical layer from the ATM layer.

Therefore, the ATM transmission system, comprising a hub station and at least one remote station, can communicate with the hub station via an air interface. In this arrangement, fill data which reproduce states of buffers in the remote stations are acquired locally in the remote stations. The fill data are forwarded to the hub station. In the hub station, bandwidth parameters are centrally calculated in each case for the individual remote stations as a function of at least the fill data. After that, the calculated bandwidth parameters are assigned to the remote stations for a transmission from the corresponding remote station to the hub station (uplink). Each remote station can convey fill data, which reproduce the state of the corresponding buffer of the respective remote station, to the hub station via a control channel. The arithmetic unit located in the hub station calculates bandwidth parameters in each case for the individual remote

stations at least as a function of the conveyed fill data. The hub station then assigns the bandwidth parameters to the remote stations via the control channel.

The arithmetic unit can also calculate media access control (MAC) parameters, the hub station also assigning the MAC parameters to the remote stations in this case.

In addition, the arithmetic unit can calculate bandwidth parameters and/or MAC parameters based upon predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface. The bandwidth parameters and/or MAC parameters can be calculated taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface.

Although modifications and changes may be suggested by those skilled in the art to which this invention pertains, it is the intention of the inventors to embody within the patent warranted hereon all changes and modifications that may reasonably and properly come within the scope of this invention.- -

{~~Description~~} **[Substitute Specification]**

{~~Dynamic bandwidth assignment in an ATM transmission system~~}**[- -Dynamic Bandwidth Assignment In An ATM Transmission System**

BACKGROUND OF THE INVENTION

Field of the Invention]

The present invention {~~relates to a method and to an ATM transmission system which provide for~~} **[generally relates to ATM (asynchronous transfer mode) transmission systems. In particular, the present invention relates to]** dynamic bandwidth assignment {~~between a hub station and at least one remote station of an ATM transmission system.~~} **[in ATM transmission systems.**

Discussion of the Related Art]

For certain applications in wireless transmission technology, point-to-multipoint configurations are the most economic solution from the point of view of equipment. In this configuration, a hub station can communicate with a number of so-called remote stations, typically situated in a cell, in full duplex mode via an air interface. In this arrangement, a two-point channel on a single transmission medium is adequate even in the uplink, i.e. from the various remote stations to the hub station. The transmission bandwidth of this channel is physically limited in correlation with the frequency spectrum provided. {~~A~~} **[In each case a]** number of logical channels {~~which~~} are {~~in each case~~} **[made]** available {~~dedicated for the communication~~} **[for communi-cation]** between a

certain remote station and the central hub station ~~{are set up}~~ by multiplexing this two-point channel.

The total bandwidth of the physical channel can be distributed asymmetrically and, in accordance with demand aspects, dynamically to the logical channels by means of so-called asynchronous methods~~{(ATM)}~~**[, such as]** asynchronous transfer mode ~~{)}~~**[(ATM)]**. For this distribution, criteria must be used in accordance with which the bandwidth requirement of a certain remote station can be weighted with respect to the competing requirement of other remote stations. The more accurately the bandwidth requirement ~~{found in this manner}~~ can be met, the more economically the physically limited bandwidth will be ~~{utilized}~~ for communication purposes.

The conditions under which the problem of dynamic bandwidth allocation is created have become apparent in recent times. **[In particular, this problem exists in the uplink, which can be a bottleneck at the central hub station in the point-to-multipoint configuration.]** The prerequisite for achieving the highest possible gain in throughput are, among other things, a mixture of various classes of traffic and the largest possible ratio between remote stations and hub stations referred to the physical bandwidth per cell. From the point of view of the operator, a charging structure ~~{which is}~~ predominantly oriented toward ~~{the}~~ data volume actually conveyed instead of the bandwidth made available ~~{permanently must prove}~~ **[proves]** to be competitive. **[**

]In summary, these conditions ~~{would}~~ **[can]** be ~~{met}~~ **[overcome]** by introducing ATM-based transmission in the so-called *fixed wireless broadband access* segment. With respect to the wireless domain, ATM ~~{profits particularly from the physically~~

~~insurmountable}~~ **[offers the best solution with respect to]** bandwidth limitation on the air interface, which can only be countered by reducing the size of the radio cells, in contrast to alternative transmission technologies and other network areas.

~~{The}~~ **[Therefore, the]** present invention ~~{has the object of solving the problem}~~ **[answers the question]** of how the total throughput of ATM traffic can be optimized in a simple manner by means of a dynamic bandwidth allocation for the logical channels.

~~{This problem exists, in particular, in the uplink, an especially probable bottleneck at the central hub station in the point-to-multipoint configuration.}~~

[SUMMARY OF THE INVENTION]

~~{According to}~~ **[It is an object of]** the present invention~~{, the object is achieved by a method or, respectively, an ATM transmission system having the features of the independent claims. The dependent claims develop the central concept of the invention in a particularly advantageous manner.~~

~~According to the invention, therefore, a method}~~ **[to provide a method and system]**for dynamic bandwidth assignment in an ATM transmission system ~~{is provided, the ATM transmission system exhibiting a hub station and at least one remote station which can communicate with the hub station via an air interface. In this arrangement, fill data which reproduce states of buffers in the remote stations are acquired locally in the remote stations. The fill data are forwarded to the hub station. In the hub station, bandwidth parameters are centrally calculated in each case for the individual remote stations as a function of at least the fill data. After that, the calculated bandwidth~~

~~parameters are assigned to the remote stations for a transmission from the corresponding remote station to the hub station (uplink).~~}**[.]**

{~~The hub station can also calculate~~} **[It is another object of the invention to provide a method and system for calculating]** media access control (MAC) parameters **[in a hub station]** and {~~assign~~} **[assigning]** them to {~~the~~} individual remote stations.

{~~The bandwidth parameters and/or MAC parameters can be calculated taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface. The fill data can reproduce the frequency with which~~} **[It is a further object of the invention to provide a method and system for reproducing the frequency when]** a predetermined fill {~~of the~~} **[relating to a]** corresponding buffer has been exceeded via a remote station within a past period.

{~~The calculated~~} **[It is yet another object of the invention to provide a method and system for calculating]** bandwidth parameters **[that]** can be temporarily stored for a number of cycles in order to be able to achieve a predetermined regulation characteristic.

{~~According to the invention, an ATM transmission system comprising a hub station and at least one remote station which can communicate with the hub station via an air interface is also provided. In this arrangement, each remote station exhibits a buffer for data to be sent out. Each remote station can convey fill data, which reproduce the state of the corresponding buffer of the respective remote station, to the hub station~~

~~via a control channel. The hub station exhibits an arithmetic unit which calculates bandwidth parameters in each case for the individual remote stations at least as a function of the conveyed fill data. The hub station then assigns the bandwidth parameters to the remote stations via the control channel.}~~ **[These and other objects of the invention will be apparent upon careful review of the following disclosure, which is to be read in conjunction with review of the accompanying drawing figures.]**

~~{The arithmetic unit in the hub station can additionally calculate media access control (MAC) parameters, the hub station also assigning the MAC parameters to the remote stations in this case.~~

~~The arithmetic unit can calculate the bandwidth parameters and/or MAC parameters taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface.~~

~~Furthermore, a circular buffer can be provided in the hub station in order to temporarily store bandwidth parameters of a number of cycles, in which arrangement the arithmetic unit can then access the contents of the circular buffer in order to achieve a predetermined regulation characteristic of the bandwidth assignment.~~

~~The invention will now be explained in greater detail with reference to exemplary embodiments and the accompanying figures of the drawings, in which:}~~ [BRIEF DESCRIPTION OF THE DRAWINGS]

Figure 1 shows a block diagram of an ATM transmission system according to the {~~invention comprising two remote stations and one hub station,~~} **[present invention;]**

Figure 2 shows a flowchart of the acquisition, calculation and assignment process according to the present invention{~~,~~}**[;]** and

Figure 3 shows an {~~actual~~} exemplary embodiment of a modulator and a demodulator {~~which can be used in~~} **[according to]** the present invention.

[DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will now be explained in greater detail with reference to exemplary embodiments and to the accompanying drawing figures of the drawings.

The] {~~Firstly, the~~} general configuration of an ATM system according to the invention is {~~described with reference to figure~~} **[shown in Figure]** 1. Figure 1 shows two remote stations 1, 2 and one hub station 3 of an ATM (asynchronous transfer mode) transmission system. The remote stations can communicate with the hub station in each case via an air interface 4. {~~Figure 1 diagrammatically shows that the~~} **[The]** remote stations can also communicate with the hub station in each case via a bidirectional control channel 13, 13* apart from the actual transmission channel 14, 14*. In contrast to the actual data transmission channels 14, 14*, the bidirectional control channel 13, 13* is used for transmitting control information which can contain{~~, in particular,~~} bandwidth parameters and MAC parameters {~~in the sense of the present invention~~}.

Each remote station 1, 2 ~~{exhibits}~~ **[has]** a buffer 5 for data to be sent out **[therefrom]**, which is connected to a modulator 6 which modulates the data of the buffer 5 to a carrier frequency in accordance with a predetermined modulation method. In this arrangement, a controller 7 which, on the one hand, can set the modulator 6 and the demodulator 8 to certain parameters and, on the other hand, can read certain parameters such as fill values of the buffer 5, in particular from buffer 5, is connected to the buffer 5, the modulator 6 and a demodulator 8.

At the hub station 3, an arithmetic unit/controller 10 ~~{which is}~~ connected to the modulator 9 and the demodulator 11 ~~{and}~~**[,]** which is also connected to a circular buffer 12 in which values of bandwidth parameters of a number of calculation and assignment cycles can be temporarily stored ~~{as will still be explained in detail later, is of significance for the present invention apart from the modulator 9 and demodulator 11 provided in the usual manner.~~

~~In the present case, it will now be described how a dynamic bandwidth allocation (bandwidth control) takes places in accordance with the present invention}~~.[

]Due to the network characteristic, the data needed for bandwidth control are initially **[made]** available **[and]** distributed in space, ~~{namely}~~ in the remote stations 1, 2. After their local decentralized acquisition in the remote stations 1, 2~~{, they are therefore}~~**[. The data is]** combined in a centralized decision entity which is resident in the hub station 3 due to the arithmetic unit/controller 10.

A decisive factor for an ATM-conformal function is that suitable parameters for describing the buffer fills are ~~{raised which}~~ **[needed. These parameters]** will be called

threshold crossing events (TCE) {~~in the text which follows (this is~~} **[herein. The TCE parameters are]** inseparably accompanied by a certain organization of the ATM traffic{~~)~~} and {~~that~~} values derived {~~precisely~~} from these TCE parameters, which are called *urgency descriptors* (UD), are combined with the connection parameters agreed in the traffic contract and **[with]** the parameters which characterize the transmission performance of the radio link. The prerequisite for this is that the local buffer output at the remote stations 1, 2 can be controlled and is deterministic in its behavior. Using suitable algorithms, values are derived on the basis of the abovementioned parameters, which characterize the allowed proportion of bandwidth in the uplink, i.e. from the respective remote station 1, 2 to the hub station 3 {~~and which additionally~~}**[. These basic values also]** describe the manner in which the transmission medium can be accessed (MAC descriptor, MAC parameters{~~)~~}**[, etc.)]**. These basic values are conveyed from the central arithmetic unit/controller 10 in the hub station 3 to the local control entities {~~(controllers)~~} **[controllers]** 7 in the remote stations 1, 2 so that the necessary adjustments to the buffer management and to the modulators 6 can be carried out there. In this process, block retransmission requests are also taken into consideration which compensate for errors in the transmission of non-real-time data, and the overhead for special coding methods which are used for conveying real-time data as a function of the environmental conditions.

Correspondingly, the demodulator 11 is then also set at the hub station 3. Since these adjustments must be made in alignment with one another in time, a certain sequence is ensured via the exchange of acknowledgements via the bidirectional control channel

13, 13*. These data are exchanged via permanent bidirectional control channels 13, 13* between the remote stations 1, 2 and the central hub station 3.

Referring to {~~figure~~} **[Figure]** 2, the sequence {~~according to the invention,~~} for acquiring fill parameters, and of the calculation and assignment of bandwidth parameters will now be explained. Firstly, the threshold crossing events (TCEs) are acquired locally in the remote stations 1, 2 in a step S1. From these TCEs, {~~so-called~~} urgency descriptors (UD) are then determined in a step S2 and transmitted to the hub station 3. In a step S3, the hub station 3 calculates from these and other parameters bandwidth parameters for the logical channels (logical channel bandwidth values, LCB) and the MAC descriptors and transmits them back to the controllers 7 of the remote stations 1, 2. When the newly assigned bandwidth (LCB) is smaller than the previously set bandwidth, new queue weight factors are set in the remote stations 1, 2 in a step S4, which factors are a final result of the calculations and are indirectly used for setting the cell rates at the interface between buffer and modulator. In a step S5, the modulator is then set for a bandwidth release and a confirmation is transmitted to the hub station 3 via the bidirectional control channel. {~~As confirmation, the~~} **[The]** hub station 3 then transmits a ready message for use of the new bandwidth parameters (LCB) back to the remote stations 1, 2 in a step S6. In a step S7, the modulator 6 of a remote station is then set for a bandwidth occupation if the new bandwidth parameter for the corresponding remote station 1, 2 is greater than the old bandwidth parameter (LCB). The new queue weight factors (QWF) are then also set correspondingly (step S8).

~~{In summary, the following data are thus}~~ **[The data]**generated in the remote stations 1, 2 **[includes: threshold]**~~{:~~

~~- Threshold}~~ crossing events (TCE) ~~{: These events}~~ **[which]** indicate that a certain fill has been exceeded in the past period~~{. This fill can relate}~~ **[relating]** to individual queues or a group of queues within a buffer**[; urgency]**~~{.~~

~~- Urgency}~~ descriptors (UD) ~~{: These}~~ **[which]** are derived from the threshold crossing events (TCE) and the classes of traffic associated with the queues~~{. Thus, they represent}~~**[, thereby representing]** a condensation of information which is aimed for simple comparability**[; and queue]**~~{.~~

~~- Queue}~~ weight factors (QWF) ~~{: They}~~ **[which]** are the final results of calculations and are indirectly used for setting the cell rates at the interface between buffer 5 and modulator 6.

[The following data are generated] In the hub station 3**[:]**~~{, the following data are generated:~~

~~- Connection parameters in the sense of predetermined}~~ connection parameters as part of a so-called traffic contract, the observance of which must be ensured in every case~~{. When}~~**[, such that when]** a connection is newly set up, these can produce an

additional bandwidth request which can make it necessary to displace lower-value traffic of adjacent remote stations**[; logical]**~~{.~~

~~-Logical}~~ channel bandwidth values ~~{: These}~~ **[which]** describe the bandwidth granted to a connection from a remote station 1, 2 to the hub station 3~~{. To}~~**[, which in order to]** achieve a certain regulation characteristic, these values are saved over a number of cycles in a circular buffer 12 which can be accessed by the arithmetic unit/controller 10 of the hub station 3**[; environmental]**~~{.~~

~~-Environmental}~~ condition descriptors ~~{: These}~~ **[which]** describe the current actual transmission characteristic of the air interface 4~~{. The}~~**[, and the]** error protection methods selected as a function of this have an influence on the bandwidth needed**[; configuration]**~~{.~~

~~-Configuration}~~ data, for example *encryption over the air*~~{. They}~~**[, which]** can have an influence on the bandwidth needed**[; and weight]**~~{.~~

~~-Weight}~~ factors derived from charging strategies for determining the bandwidth parameter values for the logical channels.

Figure ~~{3}~~ **[3A]** shows an actual implementation of a modulator and a demodulator which can be used in the present invention. The design shown in ~~{figure 3}~~ **[Figure 3A]** can be used in various switch configurations and with

modulators/demodulators which may be different and both in the remote station as in the hub station. A mixed FDMA/TDMA method, for example, is of advantage as radio transmission technique for the air interface 4.

The arrangement can be implemented on the surface of two boards equipped on one side or one board equipped on both sides. For the purpose of integration in the ATM switch 36140/144 shown, a connection to the backplane busses (cell bus technology) is provided additionally on the modulator side (MOD) in addition to coupling the local power supply unit (PSU) to the centralized power supply of the switches. For this purpose, so-called FPGAs and the CUBIT-Pro components by the Transwitch company are used which are here collectively called *bus interface to cell bus and control bus*. The cell buffer for the non-real-time traffic or the ATM traffic to be shaped is constructed with SDRAMs. The rule-based buffer management is carried out with the aid of the Siemens HL standard component ABM (PXB 4330) which is controlled centrally via its local bus connection. This component additionally has a direct interface (Utopia) with the modulator/demodulator unit and the bus interface to the cell bus for the ATM user traffic. ~~{Thus}~~ **[However]**, in real life ~~{time}~~ ATM user traffic can be forwarded between these interfaces directly via an internal bypass, i.e. by bypassing the buffer**[, as shown in Figure 3B]**. Because of its high power dissipation, the modulator/demodulator unit is taken into consideration under special requirements for the EMC compatibility, particularly in configuration technology. It is centrally controlled via a logical control interface. To control the components involved and the ATM traffic,

the so-called voyager processor by the Motorola company is used which is connected to the components via its standard interfaces (Utopia, local bus, serial interface).

~~{According}~~ **[Thus, according]** to the present invention, ~~{a method which can be used in practice is thus demonstrated by means of which}~~ the bandwidth at the air interface is dynamically assigned on the basis of connection parameters, current buffer fills, the transmission characteristics of the air interface and charging strategies, in such a manner that the transmission volume of ATM-conformal traffic in the uplink of wireless point-to-multipoint configurations is optimized, taking into consideration these and other boundary conditions. Following the ATM layer model, this can be considered to be motivated as a control of characteristics of the physical layer from the ATM layer.

~~{Patent claims~~

~~1. A method for dynamic bandwidth assignment in an ATM transmission system which exhibits a hub station (3) and at least one remote station (1, 2) which can communicate with the hub station (3), exhibiting the following steps:~~

~~- local acquisition of fill data which reproduce states of buffers (5) in the remote stations (1, 2),~~

~~- forwarding of the fill data to the hub station (3),~~

~~- central calculation (10) of bandwidth parameters in each for the remote stations (1, 2) in the hub station (3) as a function of at least the fill data, and~~

~~- assignment of the calculated bandwidth parameters to the remote stations (1, 2) for a transmission from the corresponding remote station (1, 2) to the hub station (3).~~

~~2. The method as claimed in claim 1, characterized in that the hub station (3) additionally calculates MAC parameters and assigns them to the remote stations (1, 2).~~

~~3. The method as claimed in one of the preceding claims, characterized in that the bandwidth parameters and/or MAC parameters are calculated (10) taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface (4).~~

~~4. The method as claimed in one of the preceding claims, characterized in that the fill data provide information on the frequency with which a predetermined fill of the buffer (5) of the corresponding remote station (1, 2) has been exceeded within a past period.~~

~~5. The method as claimed in one of the preceding claims, characterized in that the calculated bandwidth parameters are temporarily stored (12) for a number of cycles in order to achieve a predetermined regulation characteristic.~~

~~6. An ATM transmission system exhibiting a hub station (3) and at least one remote station (1, 2) which can communicate with the hub station (3) via an air interface (4), in which~~

~~- each remote station (1, 2) exhibits a buffer (5) for data to be sent out,~~

~~- each remote station (1, 2) conveys fill data, which reproduce the state of the buffer (5) of the respective remote station (1, 2), to the hub station (3) via a control channel (13),~~

~~- the hub station (3) exhibits an arithmetic unit (10) which calculates bandwidth parameters in each case for the individual remote stations (1, 2) at least as a function of the transmitted fill data, and~~

~~- the hub station (3) assigns the bandwidth parameters to the individual remote stations (1, 2) via the control channel (13*).~~

~~7. The ATM transmission system as claimed in claim 6, characterized in that the arithmetic unit (10) in the hub station (3) additionally calculates MAC parameters and the hub station (3) assigns these to the remote stations (1, 2).~~

~~8. The ATM transmission system as claimed in one of claims 6 or 7, characterized in that the arithmetic unit (10) calculates the bandwidth parameters and/or MAC parameters taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface (4).~~

~~9. The ATM transmission system as claimed in one of claims 6 to 8, characterized in that the fill data provide information on the frequency with which a predetermined fill of the corresponding buffer (5) has been exceeded within a past period.~~

~~10. The ATM transmission system as claimed in one of claims 6 to 9, characterized in that in the hub station (3), a circular buffer (12) for the temporary storage of bandwidth parameters of a number of cycles is provided which is accessed by the arithmetic unit (10) in order to achieve a predetermined regulation characteristic of the bandwidth assignment.~~

~~Abstract~~

~~Dynamic bandwidth assignment in an ATM transmission system~~

~~According to the present invention, a method and an ATM (asynchronous transfer mode) system are provided by means of which bandwidth is dynamically assigned on the air interface on the basis of connection parameters, current buffer fills of remote~~

~~stations (1, 2), the transmission characteristics of the radio link and charging strategies, in such a manner that the transmission volume of ATM-conformal traffic in the uplink of wireless point-to-multipoint configurations is optimized taking into consideration these and other boundary conditions.~~

~~According to the invention, a hub station (3) and at least one remote station (1, 2), which can communicate with the hub station (3) via an air interface 4 are provided for this purpose. Each remote station (1, 2) exhibits a buffer (5) for data to be sent out. Each remote station (1, 2) conveys fill data, which reproduce the state of the buffer (5) of the respective remote station (1, 2), to the hub station (3) via a control channel 13. The hub station (3) exhibits an arithmetic unit (10) which calculates bandwidth parameters in each case for the individual remote station (1, 2) at least as a function of the conveyed fill data. The hub station (3) then assigns the bandwidth parameters to the individual remote stations (1, 2) via the control channel 13*.~~

~~(Figure 1)~~

~~the physically limited bandwidths will be utilized for communication purposes.~~

~~The conditions under which the problem of dynamic bandwidth allocation is created have become apparent in recent times. The prerequisite for achieving the highest possible gain in throughput are, among other things, a mixture of various classes of traffic and the largest possible ratio between remote stations and hub stations referred to the physical bandwidth per cell. From the point of view of the operator, a charging structure which is predominantly oriented toward the data volume actually conveyed instead of the bandwidth made available permanently must prove to be competitive. In summary, these conditions would be met by introducing ATM-based transmission in the so-called *fixed wireless broadband access* segment. With respect to the wireless domain, ATM profits particularly from the physically insurmountable bandwidth limitation on the air interface, which can only be countered by reducing the size of the radio cells, in contrast to alternative transmission technologies and other network areas.~~

~~From PCT patent application WO 97/35410, a method for the dynamic bandwidth assignment in an ATM transmission system is known. This exhibits a hub station and at least one remote station which can communicate with the hub station.~~

~~The present invention has the object of solving the problem of how the total throughput of ATM traffic can be optimized in a simple manner by means of a dynamic bandwidth allocation for the logical channels.~~

~~This problem exists, in particular, in the uplink, an especially probable bottleneck at the central hub station in the point-to-multipoint configuration. According to the present invention, the object is achieved by a method or, respectively, an ATM transmission system having the features of the independent claims. The dependent claims~~

~~New patent claim 1~~

~~A method for dynamic bandwidth assignment in an ATM transmission system which exhibits a hub station (3) and at least 1 remote station (1, 2) which can communicate with the hub station (3), characterized in that a local acquisition of fill data which reproduce states of buffers (5) in the remote stations (1, 2), is carried out, in that the fill data are forwarded to the hub station (3), in that a central calculation (10) of bandwidth parameters is carried out in each case for the remote stations (1, 2) in the hub station (3) as a function of at least the fill data and in that an assignment of the calculated bandwidth parameters to the remote station (1, 2) for a transmission from the corresponding remote station (1, 2) to the hub station (3) is carried out.~~

~~1/4~~

~~2/4~~

~~4/4~~} [Therefore, the ATM transmission system, comprising a hub station and at least one remote station, can communicate with the hub station via an air interface. In this arrangement, fill data which reproduce states of buffers in the remote stations are acquired locally in the remote stations. The fill data are forwarded to the hub station. In the hub station, bandwidth parameters are centrally calculated in each case for the individual remote stations as a function of at least the fill data. After that, the calculated bandwidth parameters are assigned to the remote stations for a transmission from the corresponding remote station to the hub station (uplink). Each remote station can convey fill data, which reproduce the state of the corresponding buffer of the respective remote station, to the hub station via a control channel. The arithmetic unit located in the hub station calculates bandwidth parameters in each case for the individual remote stations at least as a function of the conveyed fill data. The hub station then assigns the bandwidth parameters to the remote stations via the control channel.

The arithmetic unit can also calculate media access control (MAC) parameters, the hub station also assigning the MAC parameters to the remote stations in this case.

In addition, the arithmetic unit can calculate bandwidth parameters and/or MAC parameters based upon predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface. The bandwidth parameters and/or MAC parameters can be calculated taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface.

Although modifications and changes may be suggested by those skilled in the art to which this invention pertains, it is the intention of the inventors to embody within the patent warranted hereon all changes and modifications that may reasonably and properly come within the scope of this invention.- -]

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Description

Dynamic bandwidth assignment in an ATM transmission system

The present invention relates to a method and to an ATM transmission system which provide for dynamic bandwidth assignment between a hub station and at least one remote station of an ATM transmission system.

For certain applications in wireless transmission technology, point-to-multipoint configurations are the most economic solution from the point of view of equipment. In this configuration, a hub station can communicate with a number of so-called remote stations, typically situated in a cell, in full duplex mode via an air interface. In this arrangement, a two-point channel on a single transmission medium is adequate even in the uplink, i.e. from the various remote stations to the hub station. The transmission bandwidth of this channel is physically limited in correlation with the frequency spectrum provided. A number of logical channels which are in each case available dedicated for the communication between a certain remote station and the central hub station are set up by multiplexing this two-point channel.

The total bandwidth of the physical channel can be distributed asymmetrically and, in accordance with demand aspects, dynamically to the logical channels by means of so-called asynchronous methods (ATM - asynchronous transfer mode). For this distribution, criteria must be used in accordance with which the

bandwidth requirement of a certain remote station can be weighted with respect to the competing requirement of other remote stations. The more accurately the bandwidth requirement found in this manner can be met, the more economically the physically limited bandwidth will be utilized for communication purposes.

The conditions under which the problem of dynamic bandwidth allocation is created have become apparent in recent times. The prerequisite for achieving the highest possible gain in throughput are, among other things, a mixture of various classes of traffic and the largest possible ratio between remote stations and hub stations referred to the physical bandwidth per cell. From the point of view of the operator, a charging structure which is predominantly oriented toward the data volume actually conveyed instead of the bandwidth made available permanently must prove to be competitive. In summary, these conditions would be met by introducing ATM-based transmission in the so-called "fixed wireless broadband access" segment. With respect to the wireless domain, ATM profits particularly from the physically insurmountable bandwidth limitation on the air interface, which can only be countered by reducing the size of the radio cells, in contrast to alternative transmission technologies and other network areas.

From PCT patent application WO 97/35410, a method for the dynamic bandwidth assignment in an ATM transmission system is known. This exhibits a hub station and at least one remote station which can communicate with the hub station.

The present invention has the object of solving the problem of how the total throughput of ATM traffic can be optimized in a simple manner by means of a dynamic bandwidth allocation for the logical channels.

This problem exists, in particular, in the uplink, an especially probable bottleneck at the central

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hub station in the point-to-multipoint configuration.

According to the present invention, the object is achieved by a method or, respectively, an ATM transmission system having the features of the independent claims. The dependent claims develop the central concept of the invention in a particularly advantageous manner.

According to the invention, therefore, a method for dynamic bandwidth assignment in an ATM transmission system is provided, the ATM transmission system exhibiting a hub station and at least one remote station which can communicate with the hub station via an air interface. In this arrangement, fill data which reproduce states of buffers in the remote stations are acquired locally in the remote stations. The fill data are forwarded to the hub station. In the hub station, bandwidth parameters are centrally calculated in each case for the individual remote stations as a function of at least the fill data. After that, the calculated bandwidth parameters are assigned to the remote stations for a transmission from the corresponding remote station to the hub station (uplink).

The hub station can also calculate media access control (MAC) parameters and assign them to the individual remote stations.

The bandwidth parameters and/or MAC parameters can be calculated taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface.

The fill data can reproduce the frequency with which a predetermined fill of the corresponding buffer has been exceeded via a remote station within a past period.

The calculated bandwidth parameters can be temporarily stored for a number of cycles in order to be able to achieve a predetermined regulation characteristic.

According to the invention, an ATM transmission system comprising a hub station and at least one remote station which can communicate with the hub station via an air interface is also provided. In this arrangement, each remote station exhibits a buffer for data to be sent out. Each remote station can convey fill data, which reproduce the state of the corresponding buffer of the respective remote station, to the hub station via a control channel. The hub station exhibits an arithmetic unit which calculates bandwidth parameters in each case for the individual remote stations at least as a function of the conveyed fill data. The hub station then assigns the bandwidth parameters to the remote stations via the control channel.

The arithmetic unit in the hub station can additionally calculate media access control (MAC) parameters, the hub station also assigning the MAC parameters to the remote stations in this case.

The arithmetic unit can calculate the bandwidth parameters and/or MAC parameters taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface.

Furthermore, a circular buffer can be provided in the hub station in order to temporarily store bandwidth parameters of a number of cycles, in which arrangement the arithmetic unit can then access the contents of the circular buffer in order to achieve a predetermined regulation characteristic of the bandwidth assignment.

The invention will now be explained in greater detail with reference to exemplary embodiments and the accompanying figures of the drawings, in which:

Figure 1 shows a block diagram of an ATM transmission system according to the invention comprising two remote stations and one hub station,

Figure 2 shows a flowchart of the acquisition, calculation and assignment process according to the present invention, and

Figure 3 shows an actual exemplary embodiment of a modulator and a demodulator which can be used in the present invention.

Firstly, the general configuration of an ATM system according to the invention is described with reference to figure 1. Figure 1 shows two remote stations 1,2 and one hub station 3 of an ATM (asynchronous transfer mode) transmission system. The remote stations can communicate with the hub station in each case via an air interface 4. Figure 1 diagrammatically shows that the remote stations can also communicate with the hub station

in each case via a bidirectional control channel 13, 13' apart from the actual transmission channel 14, 14'. In contrast to the actual data transmission channels 14, 14', the bidirectional control channel 13, 13' is used for transmitting control information which can contain, in particular, bandwidth parameters and MAC parameters in the sense of the present invention.

Each remote station 1, 2 exhibits a buffer 5 for data to be sent out, which is connected to a modulator 6 which modulates the data of the buffer 5 to a carrier frequency in accordance with a predetermined modulation method. In this arrangement, a controller 7 which, on the one hand, can set the modulator 6 and the demodulator 8 to certain parameters and, on the other hand, can read certain parameters such as fill values of the buffer 5, in particular from buffer 5, is connected to the buffer 5, the modulator 6 and a demodulator 8.

At the hub station 3, an arithmetic unit/controller 10 which is connected to the modulator 9 and the demodulator 11 and which is also connected to a circular buffer 12 in which values of bandwidth parameters of a number of calculation and assignment cycles can be temporarily stored as will still be explained in detail later, is of significance for the present invention apart from the modulator 9 and demodulator 11 provided in the usual manner.

In the present case, it will now be described how a dynamic bandwidth allocation (bandwidth control) takes places in accordance with the present invention. Due to the network characteristic, the data needed for bandwidth control are initially available distributed in

space, namely in the remote stations 1, 2. After their local decentralized acquisition in the remote stations 1, 2, they are therefore combined in a centralized decision entity which is resident in the hub station 3 due to the arithmetic unit/controller 10.

A decisive factor for an ATM-conformal function is that suitable parameters for describing the buffer fills are raised which will be called "threshold crossing events" (TCE) in the text which follows (this is inseparably accompanied by a certain organization of the ATM traffic) and that values derived precisely from these TCE parameters, which are called "urgency descriptors" (UD), are combined with the connection parameters agreed in the traffic contract and the parameters which characterize the transmission performance of the radio link. The prerequisite for this is that the local buffer output at the remote stations 1, 2 can be controlled and is deterministic in its behavior. Using suitable algorithms, values are derived on the basis of the abovementioned parameters, which characterize the allowed proportion of bandwidth in the uplink, i.e. from the respective remote station 1, 2 to the hub station 3 and which additionally describe the manner in which the transmission medium can be accessed (MAC descriptor, MAC parameters). These basic values are conveyed from the central arithmetic unit/controller 10 in the hub station 3 to the local control entities (controllers) 7 in the remote stations 1, 2 so that the necessary adjustments to the buffer management and to the modulators 6 can be carried out there. In this process, block retransmission requests are also taken into consideration which

compensate for errors in the transmission of non-real-time data, and the overhead for special coding methods which are used for conveying real-time data as a function of the environmental conditions. Correspondingly, the demodulator 11 is then also set at the hub station 3. Since these adjustments must be made in alignment with one another in time, a certain sequence is ensured via the exchange of acknowledgements via the bidirectional control channel 13, 13'. These data are exchanged via permanent bidirectional control channels 13, 13' between the remote stations 1, 2 and the central hub station 3.

Referring to figure 2, the sequence according to the invention, for acquiring fill parameters, and of the calculation and assignment of bandwidth parameters will now be explained. Firstly, the threshold crossing events (TCEs) are acquired locally in the remote stations 1, 2 in a step S1. From these TCEs, so-called urgency descriptors (UD) are then determined in a step S2 and transmitted to the hub station 3. In a step S3, the hub station 3 calculates from these and other parameters bandwidth parameters for the logical channels (logical channel bandwidth values, LCB) and the MAC descriptors and transmits them back to the controllers 7 of the remote stations 1, 2. When the newly assigned bandwidth (LCB) is smaller than the previously set bandwidth, new queue weight factors are set in the remote stations 1, 2 in a step S4, which factors are a final result of the calculations and are indirectly used for setting the cell rates at the interface between buffer and modulator. In a step S5, the modulator is then set for a bandwidth

release and a confirmation is transmitted to the hub station 3 via the bidirectional control channel. As confirmation, the hub station 3 then transmits a ready message for use of the new bandwidth parameters (LCB) back to the remote stations 1, 2 in a step S6. In a step S7, the modulator 6 of a remote station is then set for a bandwidth occupation if the new bandwidth parameter for the corresponding remote station 1, 2 is greater than the old bandwidth parameter (LCB). The new queue weight factors (QWF) are then also set correspondingly (step S8).

In summary, the following data are thus generated in the remote stations 1, 2:

- Threshold crossing events (TCE): These events indicate that a certain fill has been exceeded in the past period. This fill can relate to individual queues or a group of queues within a buffer.

- Urgency descriptors (UD): These are derived from the threshold crossing events (TCE) and the classes of traffic associated with the queues. Thus, they represent a condensation of information which is aimed for simple comparability.

- Queue weight factors (QWF): They are the final results of calculations and are indirectly used for setting the cell rates at the interface between buffer 5 and modulator 6.

In the hub station 3, the following data are generated:

- Connection parameters in the sense of predetermined connection parameters as part of a so-called traffic contract, the observance of which must be ensured in every case. When a connection is newly set up, these can produce an additional bandwidth request which can make it necessary to displace lower-value traffic of adjacent remote stations.

- Logical channel bandwidth values: These describe the bandwidth granted to a connection from a remote station 1, 2 to the hub station 3. To achieve a certain regulation characteristic, these values are saved over a number of cycles in a circular buffer 12 which can be accessed by the arithmetic unit/controller 10 of the hub station 3.

- Environmental condition descriptors: These describe the current actual transmission characteristic of the air interface 4. The error protection methods selected as a function of this have an influence on the bandwidth needed.

- Configuration data, for example "encryption over the air". They can have an influence on the bandwidth needed.

- Weight factors derived from charging strategies for determining the bandwidth parameter values for the logical channels.

Figure 3 shows an actual implementation of a modulator and a demodulator which can be used in the present invention. The design shown in figure 3 can be used in various switch configurations and with modulators/demodulators which may be different and both in the remote station as in the hub station. A mixed FDMA/TDMA method, for example, is of advantage as radio transmission technique for the air interface 4.

The arrangement can be implemented on the surface of two boards equipped on one side or one board equipped on both sides. For the purpose of integration in the ATM switch 36140/144 shown, a connection to the backplane busses (cell bus technology) is provided additionally on the modulator side (MOD) in addition to coupling the local power supply unit (PSU) to the centralized power supply of the switches. For this purpose, so-called FPGAs and the CUBIT-Pro components by the Transwitch company are used which are here collectively called "bus interface to cell bus and control bus". The cell buffer for the non-real-time traffic or the ATM traffic to be shaped is constructed with SDRAMs. The rule-based buffer management is carried out with the aid of the Siemens HL standard component ABM (PXB 4330) which is controlled centrally via its local bus connection. This component additionally has a direct interface (Utopia) with the modulator/demodulator unit and the bus interface to the cell bus for the ATM user traffic. Thus, in real life

time ATM user traffic can be forwarded between these interfaces directly via an internal bypass, i.e. by bypassing the buffer. Because of its high power dissipation, the modulator/demodulator unit is taken into consideration under special requirements for the EMC compatibility, particularly in configuration technology. It is centrally controlled via a logical control interface. To control the components involved and the ATM traffic, the so-called voyager processor by the Motorola company is used which is connected to the components via its standard interfaces (Utopia, local bus, serial interface).

According to the present invention, a method which can be used in practice is thus demonstrated by means of which the bandwidth at the air interface is dynamically assigned on the basis of connection parameters, current buffer fills, the transmission characteristics of the air interface and charging strategies, in such a manner that the transmission volume of ATM-conformal traffic in the uplink of wireless point-to-multipoint configurations is optimized, taking into consideration these and other boundary conditions. Following the ATM layer model, this can be considered to be motivated as a control of characteristics of the physical layer from the ATM layer.

Patent Claims

1. A method for dynamic bandwidth assignment in an ATM transmission system which exhibits a hub station (3) and at least 1 remote station (1, 2) which can communicate with the hub station (3), characterized in that a local acquisition of fill data which reproduce states of buffers (5) in the remote stations (1, 2), is carried out, in that the fill data are forwarded to the hub station (3), in that a central calculation (10) of bandwidth parameters is carried out in each case for the remote stations (1, 2) in the hub station (3) as a function of at least the fill data and in that an assignment of the calculated bandwidth parameters to the remote station (1, 2) for a transmission from the corresponding remote station (1, 2) to the hub station (3) is carried out.

2. The method as claimed in claim 1, characterized in that the hub station (3) additionally calculates MAC parameters and assigns them to the remote stations (1, 2).

3. The method as claimed in one of the preceding claims, characterized in that the bandwidth parameters and/or MAC parameters are calculated (10) taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface (4).

4. The method as claimed in one of the preceding claims, characterized in that the fill data provide information on the frequency with which a predetermined fill of the buffer (5) of the corresponding remote station (1, 2) has been exceeded within a past period.

5. The method as claimed in one of the preceding claims, characterized in that the calculated bandwidth parameters are temporarily stored (12) for a number of cycles in order to achieve a predetermined regulation characteristic.

6. An ATM transmission system exhibiting a hub station (3) and at least one remote station (1, 2) which can communicate with the hub station (3) via an air interface (4), in which

- each remote station (1, 2) exhibits a buffer (5) for data to be sent out,
- each remote station (1, 2) conveys fill data, which reproduce the state of the buffer (5) of the respective remote station (1, 2), to the hub station (3) via a control channel (13),
- the hub station (3) exhibits an arithmetic unit (10) which calculates bandwidth parameters in each case for the individual remote stations (1, 2) at least as a function of the transmitted fill data, and
- the hub station (3) assigns the bandwidth parameters to the individual remote stations (1, 2) via the control channel (13').

7. The ATM transmission system as claimed in claim 6, characterized in that the arithmetic unit (10) in the hub station (3) additionally calculates MAC parameters and the hub station (3) assigns these to the remote stations (1, 2).

8. The ATM transmission system as claimed in one of claims 6 or 7, characterized in that the arithmetic unit (10) calculates the bandwidth parameters and/or MAC parameters taking into consideration predetermined connection parameters and/or transmission parameters which reproduce the actual current characteristic of the air interface (4).

9. The ATM transmission system as claimed in one of claims 6 to 8, characterized in that the fill data provide information on the frequency with which a predetermined fill of the corresponding buffer (5) has been exceeded within a past period.

10. The ATM transmission system as claimed in one of claims 6 to 9, characterized in that in the hub station (3), a circular buffer (12) for the temporary storage of bandwidth parameters of a number of cycles is provided which is accessed by the arithmetic unit (10) in order to achieve a predetermined regulation characteristic of the bandwidth assignment.

Abstract

Dynamic bandwidth assignment in an ATM transmission system

According to the present invention, a method and an ATM (asynchronous transfer mode) system are provided by means of which bandwidth is dynamically assigned on the air interface on the basis of connection parameters, current buffer fills of remote stations (1, 2), the transmission characteristics of the radio link and charging strategies, in such a manner that the transmission volume of ATM-conformal traffic in the uplink of wireless point-to-multipoint configurations is optimized taking into consideration these and other boundary conditions.

According to the invention, a hub station (3) and at least one remote station (1, 2), which can communicate with the hub station (3) via an air interface 4 are provided for this purpose. Each remote station (1, 2) exhibits a buffer (5) for data to be sent out. Each remote station (1, 2) conveys fill data, which reproduce the state of the buffer (5) of the respective remote station (1, 2), to the hub station (3) via a control channel 13. The hub station (3) exhibits an arithmetic unit (10) which calculates bandwidth parameters in each case for the individual remote station (1, 2) at least as a function of the conveyed fill data. The hub station (3) then assigns the bandwidth parameters to the individual remote stations (1, 2) via the control channel 13'.

(Figure 1)

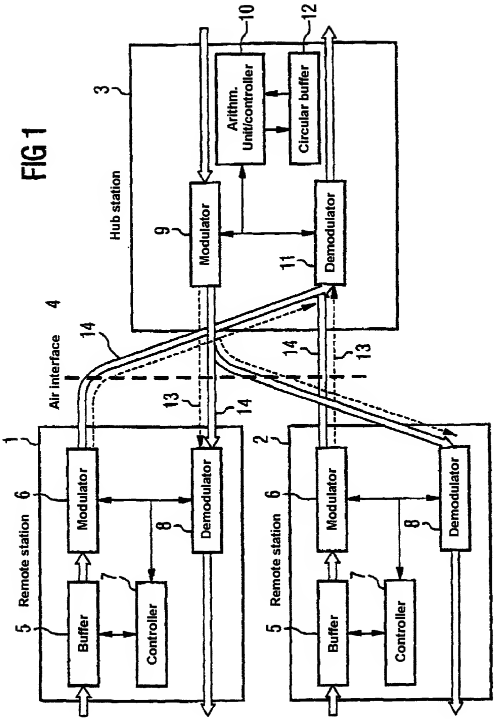
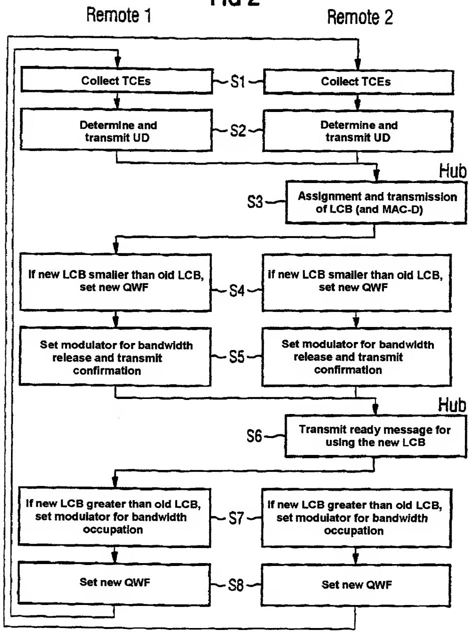

Hub station
3
Modulator
9
Arithm. Unit/controller
10
Circular buffer
12
Demodulator
11
Air interface
4
14
13
14
13
14
Remote station
1
Modulator
6
Buffer
5
Controller
7
Demodulator
8
Remote station
2
Modulator
6
Buffer
5
Controller
7
Demodulator
8

FIG 1

FIG 2


Remote 1
Remote 2
Collect TCEs
S1
Collect TCEs
Determine and transmit UD
S2
Determine and transmit UD
Hub
S3
Assignment and transmission of LCB (and MAC-D)
If new LCB smaller than old LCB, set new QWF
S4
If new LCB smaller than old LCB, set new QWF
Set modulator for bandwidth release and transmit confirmation
S5
Set modulator for bandwidth release and transmit confirmation
Hub
S6
Transmit ready message for using the new LCB
If new LCB greater than old LCB, set modulator for bandwidth occupation
S7
If new LCB greater than old LCB, set modulator for bandwidth occupation
Set new QWF
S8
Set new QWF

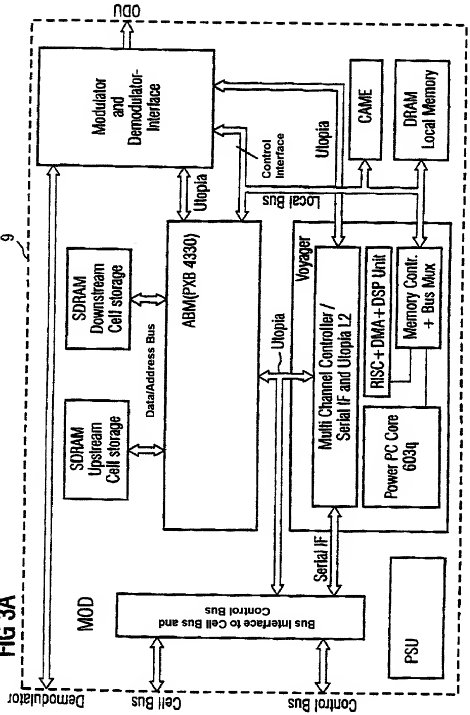
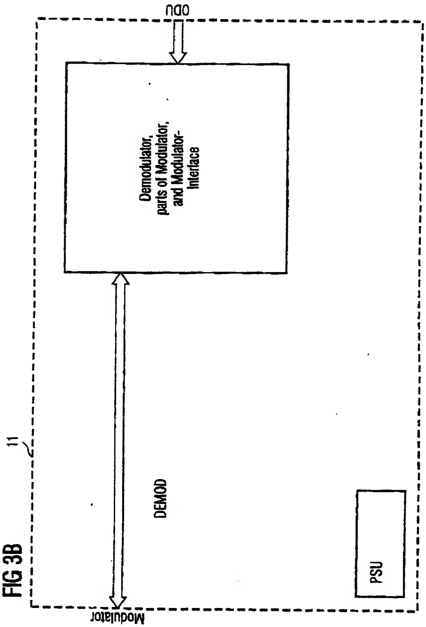

ODU
Modulator and Demodulator-Interface
Control Interface
Utopia
CAME
DRAM Local Memory
Utopia
Local Bus
9
SDRAM Downstream Cell storage
ABM(PXB 4330)
Data/Address Bus
SDRAM Upstream Cell storage
Utopia
Voyager
Multi Channel Controller / Serial IF and Utopia L2
RISC+DMA+DSP Unit
Memory Contr. + Bus Mux
Power PC Core 603q
Serial IF
MOD
Bus Interface to Cell Bus and Control Bus
PSU
Demodulator
Cell Bus
Control Bus

FIG 3A

FIG 3B


11
ODU
Demodulator,
parts of Modulator,
and Modulator-
Interface
DEMOD
PSU
Modulator

Declaration and Power of Attorney For Patent Application
Erklärung Für Patentanmeldungen Mit Vollmacht
German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

As a below named inventor, I hereby declare that:

dass mein Wohnsitz, meine Postanschrift, und meine Staatsangehörigkeit den im Nachstehenden nach meinem Namen aufgeführten Angaben entsprechen,

My residence, post office address and citizenship are as stated below next to my name,

dass ich, nach bestem Wissen der ursprüngliche, erste und alleinige Erfinder (falls nachstehend nur ein Name angegeben ist) oder ein ursprünglicher, erster und Miterfinder (falls nachstehend mehrere Namen aufgeführt sind) des Gegenstandes bin, für den dieser Antrag gestellt wird und für den ein Patent beantragt wird fur die Erfindung mit dem Titel:

Dynamische Bandbreitenzuweisung in einem ATM-Übertragungssystem

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

____

deren Beschreibung

(zutreffendes ankreuzen)

☒ hier beigefügt ist.

☐ am __________ als PCT internationale Anmeldung PCT Anmeldungsnummer __________ eingereicht wurde und am __________ abgeändert wurde (falls tatsächlich abgeändert).

the specification of which

(check one)

☐ is attached hereto.

☐ was filed on __________ as PCT international application PCT Application No. __________ and was amended on __________ (if applicable)

Ich bestätige hiermit, dass ich den Inhalt der obigen Patentanmeldung einschliesslich der Ansprüche durchgesehen und verstanden habe, die eventuell durch einen Zusatzantrag wie oben erwähnt abgeändert wurde.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

Ich erkenne meine Pflicht zur Offenbarung irgendwelcher Informationen, die für die Prüfung der vorliegenden Anmeldung in Einklang mit Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) von Wichtigkeit sind, an.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

Ich beanspruche hiermit ausländische Prioritätsvorteile gemäss Abschnitt 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 119 aller unten angegebenen Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde, und habe auch alle Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde nachstehend gekennzeichnet, die ein Anmeldedatum haben, das vor dem Anmeldedatum der Anmeldung liegt, für die Priorität beansprucht wird

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

German Language Declaration

Prior foreign appplications
Priorität beansprucht

Priority Claimed

198 27 934.5	Germany	23. Juni 1998	☒	☐
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)	Yes Ja	No Nein
			☐	☐
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)	Yes Ja	No Nein
			☐	☐
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)	Yes Ja	No Nein

Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35. United States Code. §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occured between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Serial No.) (Anmeldeseriennummer)	(Filing Date) (Anmeldedatum)	(Status) (patentiert, anhängig, aufgegeben)	(Status) (patented, pending, abandoned)
(Application Serial No.) (Anmeldeseriennummer)	(Filing Date) (Anmeldedatum)	(Status) (patentiert, anhängig, aufgeben)	(Status) (patented, pending, abandoned)

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

German Language Declaration

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POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

And I hereby appoint

Messrs. John D. Simpson (Registration No. 19,842) Lewis T. Steadman (17,074), William C. Stueber (16,453), P. Phillips Connor (19,259), Dennis A. Gross (24,410), Marvin Moody (16,549), Steven H. Noll (28,982), Brett A. Valiquet (27,841), Thomas I. Ross (29,275), Kevin W. Guynn (29,927), Edward A. Lehmann (22,312), James D. Hobart (24,149), Robert M. Barrett (30,142), James Van Santen (16,584), J. Arthur Gross (13,615), Richard J. Schwarz (13,472) and Melvin A. Robinson (31,870), David R. Metzger (32,919), John R. Garrett (27,888) all members of the firm of Hill, Steadman & Simpson, A Professional Corporation.

Telefongespräche bitte richten an: *(Name und Telefonnummer)*

Direct Telephone Calls to: *(name and telephone number)*

312/876-0200
Ext. ______

Postanschrift:

Send Correspondence to:

HILL, STEADMAN & SIMPSON
A Professional Corporation
85th Floor Sears Tower, Chicago, Illinois 60606

Voller Name des einzigen oder ursprünglichen Erfinders: HAGEN, Gunnar	Full name of sole or first inventor:
Unterschrift des Erfinders — Datum 2/7/99	Inventor's signature — Date
Wohnsitz: Santa Clara, 95050 CA USA CA	Residence
Staatsangehörigkeit: Bundesrepublik Deutschland	Citizenship
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Santa Clara, 95050 CA USA	
Voller Name des zweiten Miterfinders (falls zutreffend):	Full name of second joint inventor, if any:
Unterschrift des Erfinders — Datum	Second Inventor's signature — Date
Wohnsitz	Residence
Staatsangehörigkeit	Citizenship
Postanschrift	Post Office Address

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).

(Supply similar information and signature for third and subsequent joint inventors).

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